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Generation and visualization of earthquake drill scripts for first responders using ontology and serious game platforms

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ABSTRACT

As there is an increasing number of disasters happening worldwide, numerous mitigation approaches have been proposed to alleviate the impact of disasters. In Taiwan, public and private organizations often work together to prepare various disaster scenarios to train emergency response units. Thus, the design of appropriate drill scripts plays an important role in enhancing the capabilities of first responders in a real disaster. However, developing a reasonable drill script is a time-consuming, error-prone, and costly task. Drill scripts designed may need to accommodate time-dependent, region-specific requirements so that first responders can see varied disaster scenarios for improvement. Therefore, an ontology model with Semantic Web Rule Language (SWRL) constructs is proposed to help the drill script generation process for earthquakes in Taiwan. Drill script designers need to prepare an input data set describing a simulated earthquake using the Taiwan Earthquake Loss Estimation System, a simplified version of the Hazards U.S. – Multi Hazard (HAZUS-MH) program. Then, a drill script following pre-defined rules can be generated and combined with Unity, a serious game platform, in order to display all earthquake-related events in a virtual environment. Additional rules to accommodate varied requirements of an earthquake can be represented by customized SWRL constructs, which can be seamlessly added into the proposed drill script generation process. The developed system is demonstrated using data sets for buildings in Taiwan. During a disaster exercise, first responders can gain better situational awareness regarding an earthquake's spatiotemporal progress. Finally, it is suggested that first responders review the scene using the proposed approach immediately after a real earthquake, so that improved search and rescue plans can be defined and implemented.

1. Introduction

Nowadays, in disaster-prone regions, public and private organizations often work together to prepare various disaster exercises for their first responders or emergency response units, in the hopes of mitigating potential impacts [1,2]. According to the United States Homeland Security Exercise Evaluation Program defined by the Federal Emergency Management Agency (FEMA), a disaster exercise can be classified as either a discussion type, such as a tabletop exercise involving key personnel discussing a simulated scenario in an informal setting; or an operations type, such as a full-scale, coordinated, and supervised exercise, usually employed to test operations across multiple agencies [3]. Both types of exercises need well-designed scenarios in order to help organizations cope with a real disaster [3].

In fact, a disaster scenario can be expressed in a written form, called a drill script, which contains descriptions to mimic real-world events in accordance with a disaster's progress in a given environment [4]. It should be noted that the relationship between a disaster exercise and its drill script is different from that between a film and a film script. A film script describes instructions for actors and gives directions for filming, while a drill script does not contain instructions for first responders reacting to a disaster. Instead, a drill script includes detailed descriptions pertaining to the status of an environment and/or the evacuees as the simulation proceeds [4]. It is the first responders' responsibility to perform the so-called observe–orient–decide–act loop to practice their responses to the disaster in the simulated environment.

Previous literature has shown that the development of an appropriate drill script plays an important role in enhancing the capabilities of first responders to handle a disaster [1,4,5]. The level of a community's disaster preparedness and readiness is also highly dependent on

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the quality of the drill scripts [5]. However, creating a reasonable drill script is a time-consuming, error-prone, and costly task [4]. Several days or even weeks are usually needed in order to prepare a drill script for a large-scale emergency exercise [4]. The scope and degree of the damage described in a drill script may be incorrect, e.g., earthquake damage spotted in an area without any buildings. The sequence of events described may also be impractical, e.g., post-earthquake fires occurring before the earthquake. If the disaster scenario described in a drill script is not rational, then the disaster exercise may need to be rerun, which not only costs time and unnecessary expenditure but also puts people at risk [4]. Therefore, improvement of the drill script generation process is imperative and has been suggested for years [6].

Recently, as computer programs for estimating potential losses from disasters have improved significantly, such as the Hazards U.S. – Multi Hazard (HAZUS-MH) program published by FEMA, the impact of a disaster can be better forecast if both the disaster and the environment-related data have been accurately and completely entered into such programs [7,8]. For instance, many earthquake mitigation officials in Taiwan use the Taiwan Earthquake Loss Estimation System (TELES), a HAZUS-MH derivative with simplified functionality and local data, to estimate potential losses resulting from an earthquake hitting their administrative regions [9]. TELES is currently maintained by the Taiwan National Center for Research on Earthquake Engineering (NCREE), and its analysis results are usually of good quality [9]. Nevertheless, such a loss-estimation data set is presented in a two-dimensional format, i.e., tables, figures, and a 2D geographic information system, which cannot be directly compiled into a drill script. Important elements of a drill script, such as an event's time and physical location, are often missing from the data set [10]. Drill script designers need to refer to a digital map or urban information model of the region being analyzed, in order to fill in the missing data with assumed values [11]. In this way, although the drill script generated is more reasonable, owing to the reuse of the data set from a loss-estimation program, finalizing the disaster scenario still takes considerable time and effort.

Recently, as the technology of ontology and Semantic Web Rule Language (SWRL) has evolved dramatically, many such knowledge-based tools have been successfully applied to scenarios generation for training in different disciplines [12]. If the output of a disaster loss-estimation program and the knowledge regarding the earthquake drill script development can be combined into an ontology model with SWRL constructs, a reasonable drill script could be generated in a more effective and efficient way. Lastly, as there is an increasing number of disaster-related applications implemented using serious game technology [13], this research proposes the use of a serious game platform to visualize the generated drill script. A serious game is a digital non-entertainment-related game and it has the advantage of offering an engaging, interactive, and collaborative virtual experience, which could lead to better situational awareness for players [13]. Currently, no previous studies have investigated the application of a disaster loss-estimation program combined with a serious game platform. Such 3D-based visualization of a drill script may benefit first responders greatly because a reasonable disaster scenario can be rendered in a virtual environment. First responders can see all the events associated with a simulated disaster; hence, their capabilities of coping with the disaster could be enhanced thanks to the improved situational awareness.

Therefore, this research proposes an ontology model and system, called the Earthquake Drill Script generation and rendering System (EDSS), implemented using SWRL and Unity (a serious game platform) for generating drill scripts and for displaying a region with buildings affected by a simulated disaster. For model demonstration purposes, TELES and the digital map of regions in Taiwan are selected to supply related data to EDSS. Section 2 presents reviews of related literature, while Section 3 introduces the proposed ontology model with SWRL constructs. Section 4 illustrates the use of EDSS with data sets from TELES and local city governments. An evaluation of the proposed approach and a discussion of potential applications conclude the article.

2. Related work

This section reviews the literature regarding HAZUS-MH and disaster exercise tools relevant to this research. It also covers the techniques pertaining to ontologies and serious games that will be utilized in the development of EDSS.

2.1. HAZUS-MH

The initial version of HAZUS-MH was developed in the 1990s and was designed primarily for earthquakes [14]. Since then, it has evolved to a general-purpose natural hazard loss-estimation software tool [15]. It is freely distributed by FEMA and presently contains loss-estimation models for earthquake, flood, hurricane wind, and multi-hazard disaster types occurring in the continental U.S.A. [15]. For earthquake loss estimation, HAZUS-MH consists of an inventory database, ground motion model, building and lifeline damage models, fire-following model, direct and indirect economic loss models, and casualty model [16]. The first two components (inventory database and ground motion model) consist of the input data, while the rest of the components contain the output data. Since the quality of a software system's input data primarily determines its effectiveness, preparing the input data set has been regarded as the most important task for HAZUS-MH [16]. In the inventory database, the lowest reference unit is a census tract, and much of the building data comes from local tax assessors' files [16]. FEMA employs another tool called the Inventory Collection, Assessment and Survey Tool to facilitate the organization of the database for building and infrastructure portfolios [7]. For the ground motion model, the input data set contains various parameters of an earthquake, which can be either manually entered or automatically filled with the name of a previous earthquake.

Although HAZUS-MH and TELES share the same design methodology and database structure [9], the earthquake loss-estimation items generated by the two systems are different. For HAZUS-MH earthquake loss estimation, there are four categories: direct damage, induced damage, direct loss, and indirect economic loss [7]. The direct damage estimate includes general building stock, essential facilities, and transportation and utility lifeline systems. The induced damage estimate includes inundation, fire following, HazMat release, and debris. The direct loss estimate includes economic loss, casualties, shelter requirements, and loss of function. The indirect economic loss can be defined as the long-term effects of the direct impacts. In fact, TELES does not fully support some of the earthquake loss-estimation functions of HAZUS-MH, such as inundation, HazMat, and debris. Fewer building types are permitted in Taiwan, i.e., 15 model building types are defined in TELES while 36 types are defined in HAZUS-MH [9]. Additionally, since the economic loss data sets of HAZUS-MH provide little help to improve a first responder's capability, only the following HAZUS-MH/TELES loss-estimation items are considered and rendered in the proposed model and system: general building stock, essential facilities, fire following, and casualties.

2.2. Disaster exercise tools

Disaster exercise tools such as MASA SWORD Emergency Preparedness and TYGRON Engine have been utilized to help disaster exercise planning and implementation [17–19]. However, currently, no integration exists between such tools and disaster loss-estimation programs, despite the advanced functionality available in HAZUS-MH. Thus, it is cumbersome for the tools to reuse the loss-estimation data of HAZUS-MH in order to generate a set of more reasonable disaster scenarios. Instead, users need to either manually define each disaster-related event or at least know how to transform the output data of HAZUS-MH into comma-separated-value files, to be parsed and processed by the tools afterward [18,19].

In fact, disaster exercise planning covers many facets, including, but